NUMERICAL SIMULATION OF HEAT TRANSFER ON A CIRCULAR CYLINDER BY AN IMPINGING JET WITH NANOFLUID

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ABSTRACT

Impinging jets are a best method of achieving particularly high heat transfer over a surface circular cylinder, flat plate and concave surface are subjects of interest in many research studies over the past decades. In terms of cooling surfaces in many engineering applications had been devised to enhance the heat transfer from the jet impingement to the target surface.

In this work, a study was conducted to investigate numerically related to the jet impingement on a circular cylinder. The objective of this study is to analyze the form and nature of the distribution of heat transfer on the surface of a circular cylinder are bombarded with water and "nanofluid" as a fluid jet. Increase the heat transfer rate by using three types of "nanofluids"namely,(water+Al_2O_3), (water+ CuO) and (water + SiO_2) as a fluid jet impingement also studied..

Effects of different Reynolds numbers (Re_d) in based nozzle different the ranges of (10000-30000) the performance of jet impingement heat transfer using a water jet impingement will be compared with that using "nanofluids" as the working fluid. Simulations are carried out in the form of dimensional (3-D) and in a "steady state" by using ANSYS 14.0 software that has been commercialized in the market.

The results obtained from numerical simulations of jet impingement cooling the cylinders on the heated cylindrical tube will be presented. Heated surface of the cylinder tube will be maintained in a state of "Konstant heatflux". Geometric parameters such as the non-dimensional distance between the tip "nozzle" and the surface of the cylinder tube (h / d) was investigated in the amount of 4.8 and 12.Variasi Nusselt numbers (Nu_d) along the circumferential and axial directions obtained from this study will be reported along with numerical the flow characteristics of jet impingement. It has been observed mainly in the areas of impact that Nud increased when h/d decreases. (Nu_d) increased by 21% when the distance ratio h/d = 4 compared with the distance ratio h/d = 12.

In the present work, the nanofluid of (SiO_2 + water) gave the best heat transfer performance compared to other nanofluids and pure water. For the case of (SiO_2 + water),Re_d = 30,000, Nusselt number is 5% higher than the case of (Al_2O_3 + water). As well as same condition when use type (water + CuO), also Nusselt number decreasing in percent 8.3 % compared with type (water + AL_2O_3) and 13.3% compared with type (water + SiO_2). When using water Nusselt number decreased in percent 19% compared with the nanofluid type (water + SiO_2), means the heat transfer rate is better when using nanofluid instead of water.

ABSTRAK

Sejak beberapa dekad yang lalu, jet hentaman menggunakan cecair keatas permukaan berbentuk silinder, permukaan rata dan permukaan lengkung menjadi tumpuan yang menarik banyak kajian penyelidikan. Dari segi penyejukan permukaan dalam aplikasi kejuruteraan, banyak kajian telah dilakukan untuk meningkatkan kadar pemindahan haba dari hentaman jet ke permukaan sasaran.

Dalam penyelidikan ini, kajian telah dijalankan secara berangka untuk mengkaji berkaitan dengan jet hentaman keatas silinder bulat. Objektif kajian ini ialah mengkaji bentuk dan sifat taburan pemindahan haba diatas permukaan silinder bulat yang dihentam dengan menggunakan $H_2\,o$ dan “nanofluid” sebagai bendalir jet. Peningkatan kadar pemindahan haba dengan menggunakan tiga jenis “nanofluids” iaitu, ($H_2\,o$ + $\mathrm{SiO_2}$), (Air + CuO) dan ($H_2\,o$ + $\mathrm{AL_2O_3}$) sebagai bendalir jet hentaman juga dikaji.

Kesan dari nombor Reynolds (Re_d) yang berbeza (dalam julat 10000-30000) terhadap prestasi pemindahan haba bagi jet hentaman yang menggunakan air akan dibandingkan dengan jet hentaman yang menggunakan “nanofluids” sebagai bendalir kerja. Simulasi yang dijalankan adalah dalam bentuk e dimensi (3-D) dan dalam keadaan “steady state” dengan menggunakan perisian ANSYS 14.0 yang telah dikomersilkan didalam pasaran.

Keputusan yang diperolehi daripada simulasi secara berangka terhadap penyejukan jet hentaman berbentuk silinder keatas tiub berbentuk silinder yang dipanaskan akan dibentangkan. Permukaan tiub silinder yang dipanaskan akan dikekalkan dalam keadaan “Konstant heatflux”. Parameter geometri seperti jarak tanpa dimensi diantara hujung “nozzle” dan permukaan silinder tiub (h/d) telah dikaji dalam julah 4,8 dan 12.Variasi nombor Nusselt (Nu_d) di sepanjang arah lilitan dan paksi yang diperolehi dari kajian berangka akan dilaporkan beserta dengan ciri-ciri aliran jet hentaman. Ia telah diperhatikan terutamanya didalam kawasan hentaman bahawa Nu_d meningkat apabila h/d berkurangan. Nu_d meningkat sebanyak 21%

apabila h/d=12 berkurang kepada h/d=4.kesan h/d terhadap Nu_d hanya dapat dilihat dalam kawasan hentaman sahaja.

Dalam kajian ini,"nanofluid" yang terdiri dari campuran air dan silika oksida (H_2o + si02) memberikan presti pemindahan haba yang terbaik berbanding dengan (H_2o) tulen dan "nanofluid" yang lain. Bagi kes " nanofluids" (H_2o + SiO_2) dengan Re_d=30000, jika dibandingkan dengan "nanofluids" (H_2o +AL_2O_3), nilai nombor Nusselt (Nu_d) adalah 5% lebih tinggi. "Nanofluids" (H_2o +CuO) pula menunjukan nombor Nusselt yang lebih rendah berbanding dengan "nanofluids" (H_2o +AL_2O_3) Sebanyak 8.3% dan 13.3% lebih rendah berbanding "nanofluids"(air +sio2. Jika dibandingkan dengan air tulen, "nanofluid" (H_2o +SiO_2) menunjukkan peningkatan sebanyak 19%. Ini bermakna pemindahan haba akan menjadi lebih baik dengan menggunakan "nanofluid" berbanding air tulen terutamanya (H_2o + SiO_2).

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LIST OF SYMBOLS

k	-	Thermal conductivity (W/m k)
CuO	-	Copper Oxide
AL_2O_3	-	Aluminum Oxide
SiO_2	-	Silicic Oxide
D	-	Diameter of cylinder (mm)
d	-	Diameter of nozzle (mm)
h	-	The distance end of jet to the target a circular cylinder (mm)
dp	-	Particles diameter (nm)
ϕ	-	Volume fraction (concentration)
CFD	-	Computational fluid dynamics
Nu_d	-	Nusselt number
Re_d	-	Reynolds number
k_{eff}	-	Effective thermal conductivity
μ_{eff}	-	Effective dynamic viscosity
ρ_{eff}	-	Effective mass density
cp_{eff}	-	Effective specific heat
ρ_f	-	The mass densities of the based fluid
ρ_{nf}	-	The mass densities of solid nanoparticles

ρc_p	-	The heat capacities
θ	-	Angle
V	-	Velocity
L	-	Length
M	-	Mass
P	-	Pressure

CHAPTER 1

INTRODUCTION

1.1 Introduction

Jet impingement of fluid over a cylinder, flat plate and concave surface are subjects of interest in many research studies over the past decades. In terms of cooling surfaces in many engineering applications had been devised to enhance the heat transfer from the jet impingement to the target surface [1]. One of the most studied cooling techniques, both experimentally and numerically (for example [2], [3], [4]) in recent years. Among these studies, researchers have documented the roles of different parameters such as design, configuration, flow confinement, and turbulence on the heat transfer and fluid dynamic characteristics of jet impingement as shown figure 1.1[5].

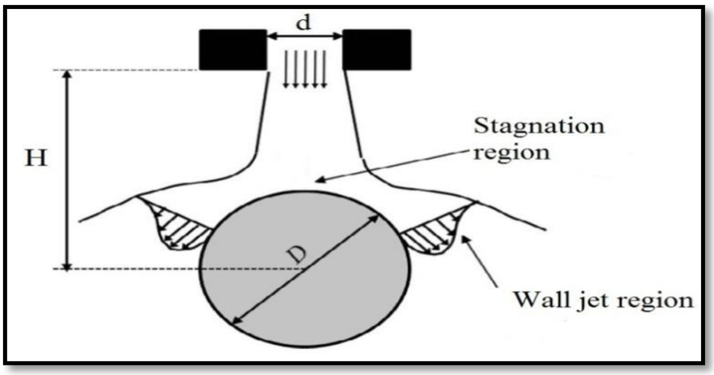

Fig1.1:Flow regions of a jet impinging on a circular cylinder [5].

This method includes the using of jet impingement with nanofluids in order to increase the heat transfer coefficient from the flow of fluid to the surface through an increase in turbulent motion. Over the past few years heat transfer enhancement by using nanofluids has gained significant attention by researchers and scientists. Preparation of nanofluids is an important step in the use of nanoparticles to improve the thermal conductivity of conventional heat transfer fluids. Researchers have experimented with different types of nanoparticles such as metallic particles (Cu, Al, Fe, Au, and Ag). Past studies showed that nanofluids exhibit enhanced thermal properties such as shown figure 1.2 and figure 1.3, higher thermal conductivity and convective heat transfer coefficients compared to the base fluid [6],[7]. With easy implementation enhanced heat transfer rates are obtained when a jet flow is directed from a nozzle of a given configuration to a target surface. Since relatively high local heat transfer coefficients are obtainable compared to no impinging flows, the use of the jet impingement technique provides the designer with a means for more effective control over the temperature of the surface under consideration.

Fig1. 2: SEM photograph of AL_2O_3 particales [8]

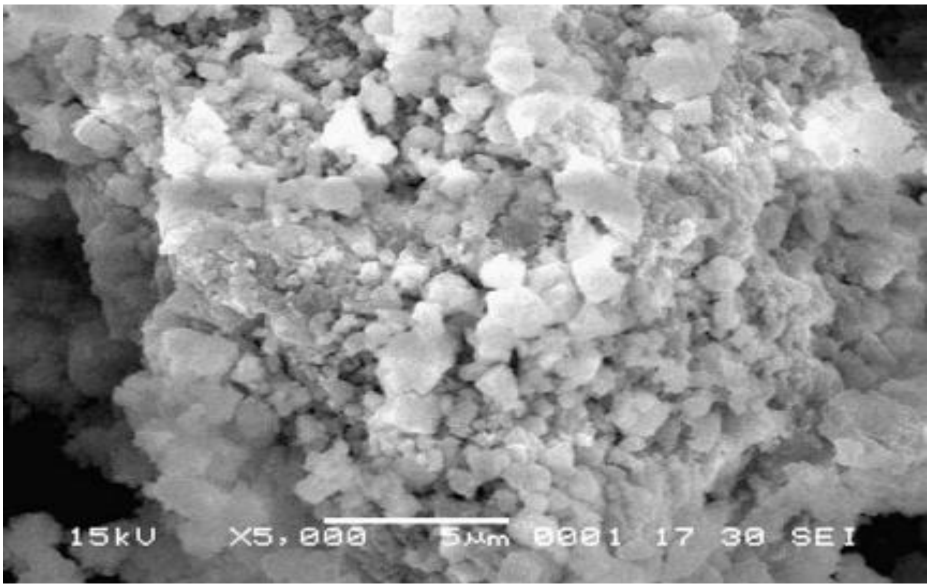

Fig1. 3: SEM photograph of AL_2O_3 particales [8].

The applications of jets impinging in various industrial processes involving high heat transfer rates use impinging jets. The jet impingements of water are used in many engineering applications such as, cooling tower, cooling, electrical devices, textiles, films and papers, processing of some metals and glass, cooling of electronic equipment. The limitation of thermo physical properties and poor thermal conductivity of conventional fluids (pure water, ethylene-glycols and engine oil). The use of solid particles as an additive suspended in the base fluid is a technique for the heat transfer enhancement. Several researchers have concluded that the use of nanofluid effectively improved the fluid thermal conductivity which consequently enhanced the heat transfer performance [9], [10]. Nanofluids showed a promising future as heat transfer fluids due its better stability and anomalous increase in thermal conductivity even for a small volume fraction of suspended nanoparticles .While thermal conductivity is directly related to heat transfer capabilities of fluids, viscosity governs the ease of flow, pressure drop and consequent pumping power involved during the transport. The advantages of utilizing the nanofluids include (i) higher thermal conductivities than that predicted by currently available macroscopic models (ii) excellent stability and (iii) negligible penalty in pumping power due to pressure drop and pipe wall abrasion, non-metallic particles (Al_2O_3, CuO, Fe_3O_4, TiO_2, and SiC) and carbon nanotubes. The thermal conductivity of nanofluids varies with the size, shape, and material of nanoparticles dispersed in the base fluids.

1.2 Problem Statement

Many equipment or appliances need to have the high heat transfer performance to guarantee the quality and also to increase the capability. For example, in supercomputers, old cooling systems cannot be used anymore as it does not cool sufficiently. This makes it necessary to develop new techniques to meet the demand. Researchers are moving toward the technology of jet impingement cooling systems. This technique becomes more interesting using multi-jet impingement cooling systems. Lots of research has to be done in this field to make sure all capabilities required will be achieved.

There is an application in cement plant، where, there is problem in rotary kilns, and this problem is high temperatures in kiln shell, therefore, need to local remedy to several areas in rotary kiln and can that using an impinging jet to remedy of high temperatures. Is necessary to local remedy to several areas in cement plant and can that using an impinging jet with nanofluid to remedy of high temperatures in power plants , there is problem in cooling towersthis problem is high of temperatures in condensers.

1.3 Project Objectives

This study is conducted to investigate numerically the jet impingement of fluids over the cylinder. The objectives of the present study are:

1) To study the distribution heat transfer on smooth circular cylinder by impingement jet cool with using water.
2) To use various types of nanofluid such as (water + AL_2O_3),(water + CuO) and (water+ SiO_2) for the enhancement of heat transfer.
3) To study the effects of different Reynolds numbers (Re_d) in the ranges of (10000-30000) on the thermal field and compare the results with pure water.

1.4 Scope Of The Study

The scopes of this project will comprise the boundaries of project study. Many characteristics should be bound in order to make this project achieve the objectives. This numerical study will carry out using nanofluids as the coolant medium that impinge with turbulent flow region from the nozzle to the heat source.

1) Reynolds number used at range (10000,15000, 20000, 25000 and 30000).
2) The distance (h) between the end nozzle to the target a circular cylinder ranges of ratio h/d are (4,8 and 12).
3) Using three types from nanofluid (water + SiO_2),(water + CuO) and (water +AL_2O_3) as fluid coolant. Concentrations nanoparticles (AL_2O_3, SiO_2 and CuO) were 4% and the diameter (dp) 30nm.
4) Using one type of nozzle was a circular nozzle with diameter (d) 6mm, length(L) was 50mm and diameter (D) of a circular cylinder was 50mm show in figure 1.4.

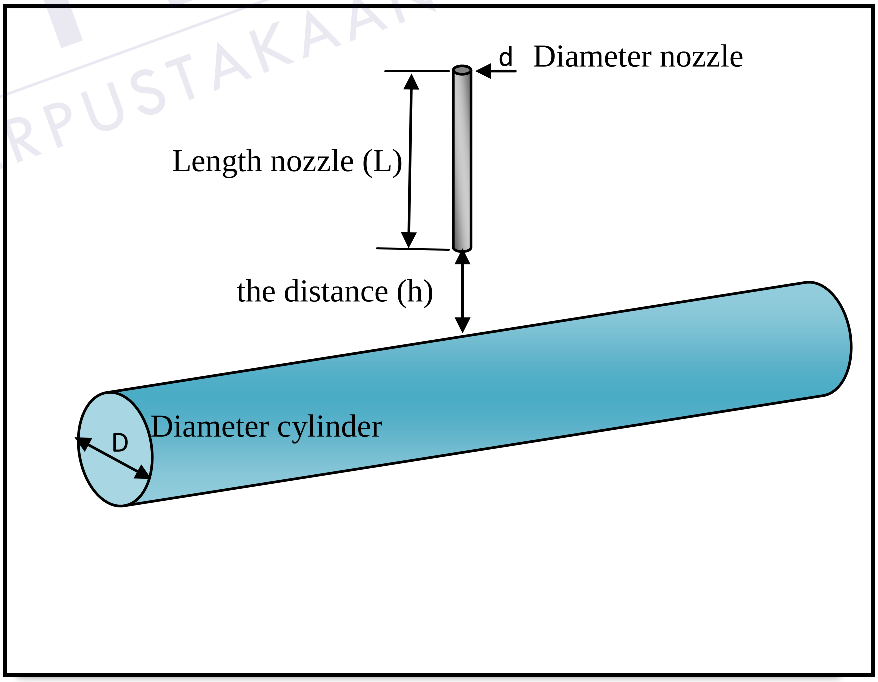

Figure1.4 Jet impingement on a circular cylinder.

1.5 Research Significance

This cooling method (nanofluids) has been used in a wide range of industrial applications such as annealing of metals, cooling tower of power plants, cooling in grinding processes, and cooling of electrical devices.Jet impingement has also become a viable candidate for high-powered electronic and photovoltaic thermal management solutions and numerous jet impingement studies have been aimed directly at electronics cooling. Jet impingement with nanofluid is an attractive cooling mechanism due to the capability of achieving high heat transfer rates.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Jet impingement on different surfaces had been a subject of interest for scientists and researchers in the past decades. Impinging Jets had attracted much research from the viewpoint of the fluid flow characteristics and their influence on heat transfer. Numerical and experimental studies had been reported in order to increase the amount of heat transferred by different techniques of jet fluids. Literature reviews on Jet impingement on circular cylinder and jet impingement by using nanofluids on different surfaces. The overall objective of the current research is to conduct a fundamental investigation of the heat transfer mechanisms for an impinging nanofluids jet. This chapter has been divided into three actions. The first section details the research concerned with the jet on circular cylinder. The second section presented the research conducted into heat transfer to an impinging jet by using nanofluids. The variation of the heat transfer with various test parameters is discussed and related to what is known of the fluid flow. A third section summarises some of the novel techniques that have been employed to enhance the heat transfer to an impinging nanofluids jet.

2.2 Heat Transfer Characteristic Of Jet Impingement

A jet is a rapid flow of fluid forced out of the small opening. The submerged jet is called as when it came out in the same fluid jet. The flow field of jet impingement can be divided three characteristic regions such as the free jet region, the impingement region and the wall jet region by [11] . Figure 2.1 shows a typical surface impingement caused by jet [12]. The region of free jet is not affected by the impinging on the target surface. The impingement region is characterized by an increase the stagnation pressure (static) as a result of the sharp decline in the mean axial velocity. After deflecting the impingement flow and began to speed up along the impingement surface. The wall jet region is characterized by higher velocity surrounding by the lower velocity at both sides, one due to the presence on the wall and another one due to the stagnant fluid. Along the impingement surface also grow up by boundary layer.

Three characteristic regions shown by the free jet region, namely the potential core region, developing flow region and developed flow region depending on the distance nozzle exit to target plate. The potential core region has the axial velocity of the flow is very similar to jet entrance. The end of the potential core is determined by the growth rate of two mixing layers originating at the edges of the nozzle. In the developing flow region, the axial velocity begins to decay and the jet spreading to the surrounding areas. Finally the axial velocity profile approaching the bell shape. The axial profiles exist from the nozzle at different jet lengths is similar in the developed flow region. Dependent distance from the nozzle to impinging target plate, the free jet region can display one or more of the above regions surface. Mostly laminar jets can turn turbulent due to mixed at the outer of jets boundary. Exactly how fast an initially transform of a laminar jet into a turbulent can depend on many factors such as confinement, the velocity profile at the nozzle exit, the jet inlet Reynolds number etc.

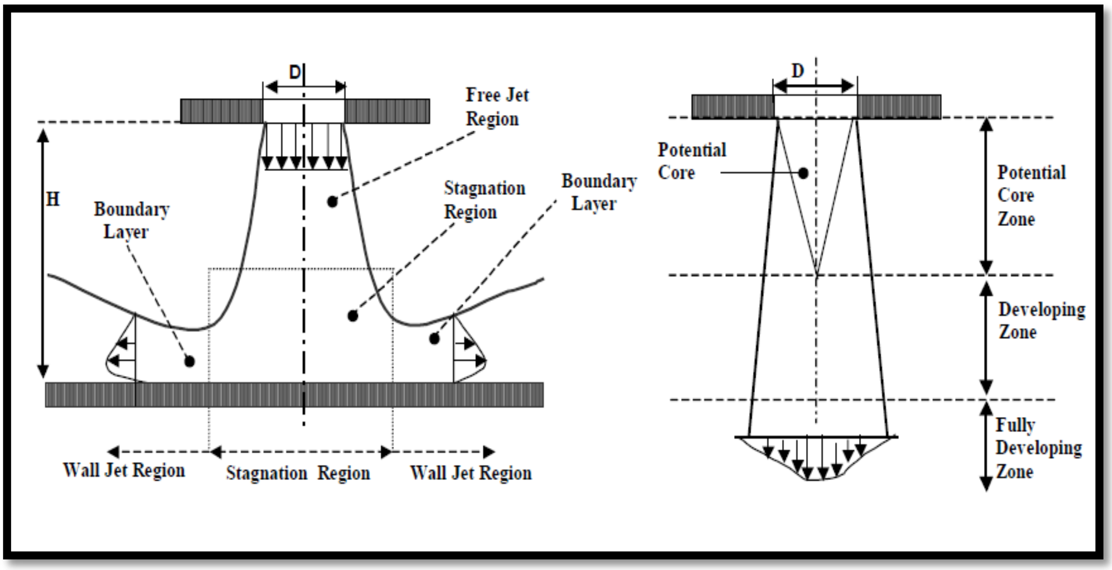

Figure 2.1: Comparison of flow regions in an impingement jet with flow regions of free jet [12].

2.3 Jet Impinging On A Concave Surface

Observed that for a concave surface impingement, in general the flow structure is more unsteady than that found in jet impingement on flat and convex surfaces. The reason for this is the centrifugal forces generated by the interaction between the flow and the concave surface act to destabilize the flow, promoting unsteadiness [13]. Figure 2.2 shows flow structures for an impinging jet with h/d = 4, 3, 2 and 1 for jet diameter d = 72.6 mm and a low Reynolds number, Re_d= 6,000. In general, similar observations were found in those of the flat plate impingement, such as the absence of large vortex structures in the primary jet due to lack of distance for vortex development for h/d = 2 and h/d = 1 (Figure 2.4 (c) and (d), respectively). However, for the concave surface, there is also an absence of large vortex structures along the primary jet at h/d = 4 and h/d = 3 (Figure 2.4 (a) and (b), respectively) due to the jet exhaust entraining into the primary jet which disrupts the formation of these large vortices. With regards to vortices on the wall, only small vortices are seen for h/d = 2 and h/d = 1 (Figure 2.4 (c) and (d), respectively), although they maintain their identity a lot longer than those on the flat plate, helped by the recirculation of the exhaust flow.

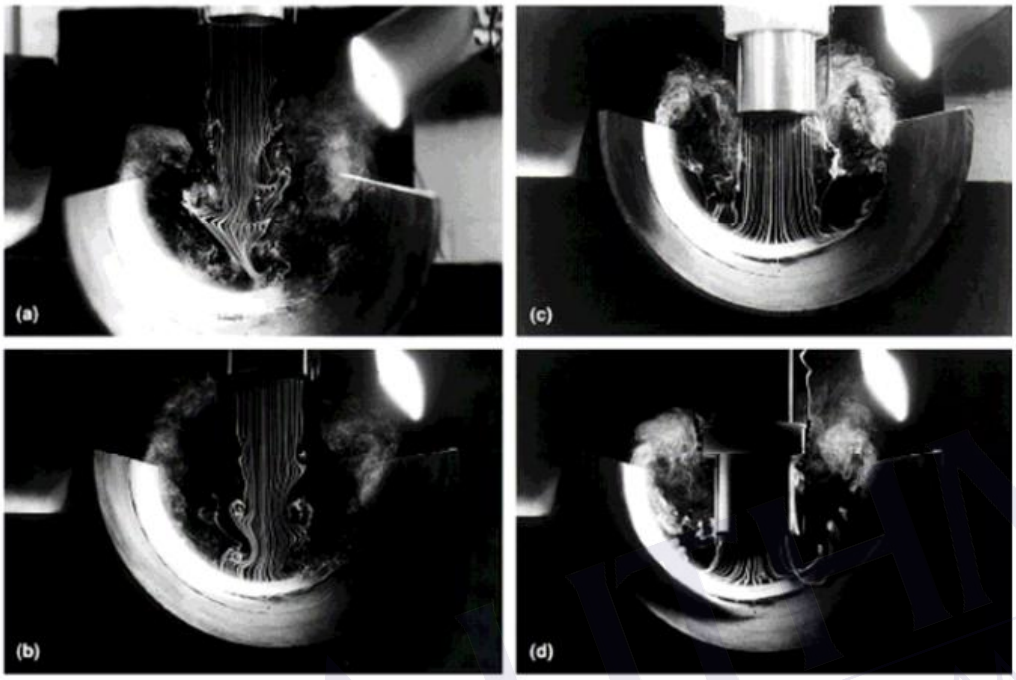

Figure 2.4: Flow structures of a jet impinging on a concave surface for (a) h/d= 4 (b) h/d = 3 (c) h/d = 2 (d) h/d = 1. jet diameter, d = 72.6 mm at Re_d= 6,000 [13].

2.4 Jet Impinging On Flat Plate

Study effects of inclination of an impinging two dimensional slot jet on the heat transfer from a flat plate. Their results showed that the location of the maximum heat transfer was mainly due to the angle of inclination. In the case of α=0°, there is normal jet impingement on the plate and the heat transfer, distribution is symmetrical around the central point of the test plate [14]. As the plate angle increases, the maximum heat transfer point shifts towards the uphill side of the plate from the geometrical impingement point. At the maximum inclination angle of 45°, the heat transfer on the downhill side of the plate is higher than that on the uphill side. The value of the maximum Nusselt number(Nu_d) gradually increases at lower jet-to-plate spacing, as the inclination angle increases. With the larger spacing of 6, the amount of increase in the maximum heat transfer point decays gradually. As the jet-to-plate distance is further increased to h/d=10, the distributions of the Nusselt number(Nu_d) are almost the same level at all angles of incidence but there is a small displacement of maximum heat transfer point. As the Reynolds number increases, the local Nusselt number(Nu_d) also increases. The increment in the Nusselt number(Nu_d) increases with increasing the Reynolds number, especially outside of the maximum heat transfer region [14].

Study the heat transfer, distribution for an impinging laminar flame jet to a flat plate. Their results clearly show that the heat flux is constant for large flame tip-toe plate distances and increases rapidly for shorter distances, which is in agreement with the analytical heat–flux relations. Moreover, the temperature measurements show good agreement with the heat–flux relations applicable a tradial distances away from the hot spot [15].

2.5 Jet Impingement On Circular Cylinder

Study experimentally the cooling of a cylinder with a rectangular jet of the same width were the choice of the jet height and the distance between the jet exit and the cylinder. The experimental measurements of the heat transfer on a cylinder, with diameter D = 10 mm, cooled by rectangular jets with low turbulence, the same width of the cylinder, but different height, H, 2.5 and 5 mm, respectively, in order to study their influence on the local and the mean cooling rates [16]. The cylinder to be cooled is heated by electric current and is set on the symmetrical plane of symmetry, i.e. the geometry is two-dimensional, at several distances from the jet exit, x, in order to find the position which realizes the maximum heat transfer. The experimental measurements of the local heat transfer were performed along the circumference of the cylinder at several angles from the impingement for Reynolds number, defined by the cylinder diameter, D, and the average velocity, in the range Re_d = 5000–22,000. The comparison between the two slots was performed at the same Reynolds number, Re_D, which means that the smaller slot had a slightly greater maximum velocity. The experiments showed that at the impinging point the local Nusselt number was greater for the slot with H = 2.5 mm, while at greater angles from the impingement, i.e. 45°, 90°, 135° and 180°, the local Nusselt numbers had different behaviors. The mean Nusselt numbers were similar for the two slots, at the same Reynolds number, Re_d. Local and mean Nusselt numbers, obtained with the two jets, are in qualitative agreement if they compare with the dimensions distance, x/H, which can be interpreted as the ratio of the Reynolds numbers, independent of the mass flow rate or per unit of mass flow rate. The maximum of the local Nusselt number of the impinging point is obtained at greater distances for smaller Reynolds numbers, e.g. in the range from x/H = 15 at Re_d = 5000 to x/H = 9 at Re_d = 22,000, while the distance is shorter along the cylinder at greater angles from the impingement. The maximum of the mean Nusselt number is similar to that on the impingement for the two jets. The experimental heat transfer is also examined from the point of view of the slot efficiency, i.e. taking into account the mechanical power necessary to move the fluid in the slot jet. The conclusion is that the smaller slot, H = 2.5 mm or D/H = 4, has a greater efficiency as cooling system because it removes more heat at the same mechanical power.

Study experimentally the turbulent air jet impinging on a square cylinder mounted on a flat plate. Turbulence statistics and flow's topology were investigated. When the surface was heated through uniform heat flux, the local heat transfer coefficient was measured [17]. The jet from a long round pipe, 75mm pipe diameters (D) in length, at Reynolds number of 23,000, impinged vertically on the square cylinder (3D , 3D , 43D). Measurements were performed using particle image velocimetry, flow visualization using fluorescent dye and infrared thermography. The flow's topology demonstrated a three-dimensional recirculation after separating from the square cylinder and a presence of foci between the bottom corner and the recirculation detachment line. The distribution of heat transfer coefficient was explained by the influence of these flow's structures and the advection of kinetic energy. On the impingement wall of the square cylinder, a secondary peak in heat transfer coefficient was observed. Its origin can be attributed to very pronounced shear production coupled with the external turbulence coming from the free jet.

Investigated numerical the flow and heat transfer predictions of multiple slot air jets impinging on circular cylinders using CFD (computational fluid dynamics). The distribution of Nusselt numbers around the cylinders of different Reynolds numbers (23,000– 100,000), distances between the jets, and the openings between them was determined for two and three jets and compared to simulations of a single jet. The flow characteristics and the heat transfer, distribution around the cylinders were found to be dependent on the distance and the opening between the jets [18]. The interaction between two jets was found to be most advantageous. The heat transfer increased for higher Reynolds number in general; for two jets the heat transfer in the stagnation point is:

$$Nu_d = 0.20 * Re * 0.68 \tag{2.1}$$

For three jets, the heat transfer, distribution is different on the outer cylinders, as compared to the cylinder in the center. Tested experimentally and numerically the turbulent circular air jet impingement cooling of a circular heated cylinder. At the surface of the heated cylinder, a constant heat flux condition was maintained. The Reynolds number, Red, defined based on the nozzle diameter, was varied from 10,000 to 25,000. The geometric parameters such as the non-dimensional distance between the nozzle exit and the circular cylinder, h/d, and the ratio of nozzle diameter to the diameter of the heated target cylinder, d/D, were investigated in the range of 4–16 and 0.11–0.25, respectively [19]. The local Nusselt number variants along the circumferential and axial directions obtained from the experimental studies were reported. To understand the flow features and to obtain the temperature and local Nusselt number distributions over the surface of the heated cylinder, a numerical study was also performed. It was observed that the stagnation Nusselt number increases monotonically as the h/d decreases and the effects of h/d and d/D are significant only in the jet impinging region. Based on the experimental results, a correlation of the stagnation Nusselt number has also been developed. Solved an inverse algorithm based on the conjugate gradient method and the discrepancy principle is applied to estimate the unknown space-and time-dependent heat flux at the surface of an initially hot cylinder cooled by a laminar confined slot impinging jet from the knowledge of temperature measurements taken on the cylinder’s surface [20]. It was assumed that no prior information is available in the functional form of the unknown heat flux; hence the procedure is classified as the function estimation in inverse calculation. The temperature data obtained from the direct problem were used to simulate the temperature measurements, and the effect of the errors in these measurements upon the precision of the estimated results is also considered. The results showed that an excellent estimation on the space-and time-dependent heat flux can be obtained even the distributions of thermal properties inside the cylinder is unknown.

Investigated experimentally the heat transfer characteristics of a rotating cylinder under lateral air impinging jet. The height and diameter of the cylinder were fixed, and the variable parameters were as follows: (1) the jet Reynolds number ($Re_{d}j$ = 655–60237); (2) the rotational Reynolds number (Re_{d}= 1975–7899); (3) the ratio of the cylinder diameter (D) to the nozzle width (w) (D/w = 2–16); (4) the relative jet-impinging distance (L/w = 1–16, L was the shortest nozzle-to-cylinder distance). This experiment measured detailed temperature on the heated wall surface of the cylinder using an infrared thermo tracer, and observed the smoke flow characteristics of the stationary and rotating cylinder under impinging jet flow using visualization techniques [21]. The experimental results showed that the rotation changed the separation position of impinging jet flow on the cylinder, and allowed the surface temperature of the cylinder to tend towards uniformity along the circumferential direction of the cylinder. In addition, the heat transfer experiment included the pure rotating condition, the pure jet-flow condition and the coexistent condition of rotation and jet flow. The results showed that the average Nusselt number (Nu_{d}) increased with the increase of Re_{d}, and decreased with the increase of D/w. The influence of D/w on Nu decreased with the increase of L/w, and Nu first increased and then decreased with the increase of L/w. In other words, there is a critical L/w value that can produce the highest Nu, and the critical L/w value increased with D/w. Finally, this study proposed reasonable and accurate empirical correlations of Nu in view of the three test conditions. All the results provided a reference for practical design of the cooling system in relevant power machinery.

Investigated using computational fluid dynamics (CFD) the Heat transfer from a slot air jet impinging on a cylinder shaped food product placed on a solid surface in a semi-confined area. Simulations of a cylinder in cross flow with the k–ε, k–ω and SST models in CFX 5.5 were compared with measurements in the literature. The SST model predicts the heat transfer better than the other models and was therefore used in this study [22]. The distribution of the local Nusselt numbers around the cylinder for various Reynolds numbers (23,000–100,000), jet-to-cylinder distances, H=d (2–8), and cylinder curvature, d=D (0.29–1.14) was determined. The results showed that the local Nusselt numbers varies around the surface of the cylinder and that the average Nusselt number and the stagnation point Nusselt number increases with increasing Reynolds numbers and surface curvature but has little dependency on the jet-to-cylinder distance. The result was

$$\mathrm{Nu_d} = 0.14\, Re^{0.65} \left(\frac{H}{d}\right)^{-0.007} \left(\frac{d}{D}\right)^{0.32} \tag{2.2}$$

And

$$\mathrm{Nu_d} = 0.46\, \mathrm{Re_d}^{0.59} \left(\frac{H}{d}\right)^{-0.026} (d/D)^{0.32} \tag{2.3}$$

Investigated numerically had been performed two-dimensional slot impingement onto two heated cylinders with different diameters turbulent flow conditions. Height of slot jet is taken as constant in all cases. The study was performed to see the effects of effective parameters on heat and fluid flow as jet Reynolds number ($11,000 \leq Re \leq 20,000$), diameter ratio of cylinders ($0.5 \leq D1/D2 \leq 1.5$) and ratio of distance between cylinders to slot jet high (L/S). Streamlines, isotherms, local and mean Nusselt numbers and CFD coefficient were obtained. These results were compared with earlier experimental and numerical works and good agreement was obtained. It was also found that diameter ratios of cylinders can be a central element for heat and fluid flow[23].

Study experimentally the enhancement of heat transfer on a cylinder due to the turbulence of the impinging jet. Experiments are carried out to cool a smooth cylinder, electrically heated, with a submerged slot jet of air at Reynolds numbers equal to $\mathrm{Re_d}$ = 4180 and $\mathrm{Re_d}$ = 7630. The increase of turbulence is obtained by the introduction of a metal grid and by the natural evolution of the jet with the distance from the slot exit. Turbulence, velocity and heat transfer measurements were presented in order to show the relation with the slot-to-cylinder distance. The metal grid is set in two positions: just on the slot exit or at a constant distance in front of the cylinder. In the natural evolution of the free jet the turbulence increases with the distance because of the interaction with stagnant air, reaches a maximum and then decreases [24]. If the grid is on the slot exit the turbulence increases at first, then decreases according to the degeneration law, and finally increases again due to the interaction with the stagnant air. Turbulence at a distance of 10 times the slot height is about the same weather was present or not the grid. Heat transfer measurements were presented as local and mean Nusselt numbers. Without grid local and mean Nusselt numbers increase with the distance from the slot exit reaching the maximum at a distance of about 8 time the slot height. With the grid on the slot exit the local Nusselt number had a maximum immediately after the grid and a minimum at 4e5 time the slot height. With the grid in front of the cylinder at the distance of the slot height the local Nusselt number had the maximum immediately after the grid and then is about constant up to 10 times the slot height. The mean Nusselt number with the grid in front of the cylinder is greater than without the grid only at the higher Reynolds number experimented.

2.6 Fundamentals of Nanofluids

Conventional heat transfer fluids such as water, oil, and ethylene glycol mixture are poor heat transfer fluids, the thermophysical properties of these fluids play important role on heat transfer coefficient. In the past years, many different techniques were used in order to improve the thermal conductively of these fluids and reach a satisfactory level of thermal efficiency. The heat transfer rate can passively be enhanced by improving thermophysical properties with adding small solid particles in the fluid. Maxwell was the first to show the possibility of increasing thermal conductivity of a solid/liquid mixture by more volume fraction of solid particles. He used particle of micrometer or millimeter dimensions. Those particles were the cause of numerous problems, such as abrasion, clogging, high pressure drop and poor suspension stability. Therefore, a new class of fluid for improving thermal conductivity and avoiding adverse effects due to the presence of particles is required. To meet these important requirements, a new class of fluids, called nanofluids has been developed [36]. Nanofluids are liquid suspensions of nano-sized particles. These particles have attracted significant attention since anomalously large enhancements in effective thermal conductivity at low particles concentration were reported.

2.7 Jet Impingement Of Nanofluid

Investigated experimentally and theoretically of spray cooling with a solid jet nozzle was performed to assess the associated heat transfer coefficients (HTC) using water/alumina nanofluids. Based on a the rmalprobe embedded in a heated testing plate, the cooling curves, which represent the transient temperature variations of the plate, have been measured at various spraying conditions. An inverse heat transfer technique was then applied to convert these measured cooling curves into the HTC. The results indicated that, after its first peak, the HTC became very stable with the associated standard deviation less than 3% of its mean and the single mean value could reliably represent the performance of spraying cooling for all cases considered. The results also showed that the HTC increased with the flow rate intensities, following a power-law type of correlation [25]. By comparing the nanofluid results with that of pure water, it was found that an approximately 45% decrease of HTC of spray cooling with the volume fraction of the nanoparticles us pension increasing from(0 to 0.1645). The reduction of HTC caused by the change of the spraying impact duration due to the presence of nanoparticles was specifically analyzed and an analytical for mulato correlate this effect was developed to further explain the combined effects of nano-particles on HTC.

Carried out Experimental study on the performance of sub cooled flow boiling heat transfer with jet impingement of FC-72 over silicon chips (10 × 10× 0.5) mm^3. Four kinds of micro-pin-fins with dimensions of (30 × 60, 30 ×120, 50×60, 50 × 120) mm^2 (thickness t= height h) were fabricated on the chip surfaces by using the dry etching technique [26]. The experiments were made at two different liquid sub cooling (25 C° and 35 C°), three different cross flow velocities v_c (0.5, 1, 1.5) m/s and three different jet velocities v_j(0, 1, 2) m/s. A smooth surface was also tested for comparison. The results show that both the microstructure and impingement give a large enhancement on heat transfer. The maximum allowable heat flux increases with the velocity and liquid sub cooling. For a fixed v_c, the enhancement degree increases with v_j especially for v_c= 0.5 m/s, v_j= 2 m/s. As v_c increases, the heat transfer enhancement ofjet impingement weakens and the increase rate of CHF (the critical heat flux) also decreases. The largest value of quad (the maximum allowable heat flux) can reach 167 W/cm^2 for chip with the fin dimension of $50mm^2$ _ $120\ mm^2$ at the condition of v_c = 1.5 m/s, Vj = 2 m/s and liquid sub cooling of 35 c°. In this paper, the jet liquid impingement heat transfer characteristics in the mini-rectangular fin heat sink for the central processing unit of a personal computer are experimentally investigated. The experiments are tested with three different channel width heat sinks under real operating conditions: no load and full load conditions. The jet liquid impingement cooling with mini-rectangular fin heat sink system is introduced as the active and passive heat transfer enhancement techniques [27].

Effects of relevant parameters on the central processing unit temperature are considered. It is found that the central processing unit temperatures obtained from the jet liquid impingement cooling system are lower than those from the conventional liquid cooling system; however, the energy consumption also increases. The results of this study are of technological importance for the efficient design of cooling systems of personal computers or electronic devices to enhance cooling performance. Heat transfer enhancement capabilities of coolants with suspended metallic nanoparticles inside typical radial flow cooling systems are numerically investigated in this paper. The laminar forced convection flow of these nanofluids between two coaxial and parallel disks with central axial injection has been considered using temperature dependent nano-fluid properties. Results clearly indicate that considerable heat transfer benefits are possible with the use of these fluid/solid particle mixtures [28].

For example, (Water/AL_2O_3) nanofluid with a volume fraction of nanoparticles as low as 4% can produce a 25% increase in the average wall heat transfer coefficient when compared to the base fluid alone (i.e., water). Furthermore, results show that considerable differences are found when using constant property nano-fluids(temperature independent) versus nanofluids with temperature dependent properties. The use of temperature-dependent properties make for greater heat transfer predictions with corresponding decreases in wall shear stresses when compared to predictions using constant properties. With an increase in wall heat flux, it was found that the average heat transfer coefficient increases whilst the wall shear stress decreases for cases using temperature-dependent nanofluid properties.

In this study, nanofluids were introduced into jet arrays impingement as the working fluid. The heat transfer features of the nanofluids were experimentally investigated. Four different Cu-nanoparticle volume fractions ranged from

(0.17 Vo 1% to 0.64 Vo l%) and two dispersant sodium do dactyl benzoic sulfate(SDBS) mass concentrations varied from (0.05 wt% to 0.1 wt%) were involved. The influences of the nanoparticle volume fraction and the dispersant SDBS on the heat transfer of nanofluids were discussed [29].

The experimental results show that the suspended nanoparticles increase the heat transfer performances of the jet arrays impingement cooling system. It had also been found that compared with the case of using nanofluids without any addition of dispersant, the nanofluid with dispersant led to a great deterioration on impingement heat transfer coefficient and even the heat transfer coefficients were smaller than that of the base liquid. pray cooling using aqueous titanic nanofluids was studied. The temperatures of a testing plate under various spraying conditions were first measured; an inverse heat conduction technique was then applied to convert these measured temperatures into heat transfer coefficients (HTCs). It was found that the HTC increased logarithmically with the volume flux, but was decreased with the increase of the nanoparticle fraction [30].

A correlation analysis was performed to quantify the HTC reduction caused by the increase of nanoparticles, and reconfirmed that the major cause for the HTC reduction was the difference in the impact (or impingement) behavior between solid nanoparticles and fluid droplets. A comparison study of the present findings with the previous published results was also performed and indicated that all results compared were consistent to each other based on the similar spray cooling conditions with different nanofluids or nozzles. The effects by using aquatic titanic nanofluids instead of aquatic alumina nanofluids and by using full-cone nozzle instead of solid jet nozzle were specifically assessed and the as so ciatedrationales for the differences in these effects were given.

The paper study mathematical modeling is performed to simulate the forced convection flow of (AL_2O_3–water) nanofluid in the radial flow cooling system using a single-phase approach. Computations are validated with experimental data available in the literature. Results show the same trend as revealed in most of the published works that the heat transfer coefficient increases with the increase of the Reynolds number and the nanoparticle volume fraction, though the increase in pressure drop is more significantly associated with the increase of particle concentration [31].

When taking both the cooling performance and the adverse effect of pressure drop into consideration, no better heat transfer enhancement is found with the use of nanofluid compared to that of pure water under the laminar, medium-heat flux conditions in the radial flow system. Furthermore, the model considering Hamilton–Crosser formula for effective conductivity along with the equation developed by Brinkman for effective viscosity of nanofluid might result in the over prediction of the capability of applying nanofluids to remove heat. Table 2.1 as shown below The thermo-physical properties of water and different nanoparticles at T=300K.

Thermo-physical Properties	**Water**	**Al_2O_3**	**CuO**	**TiO_2**	**SiO_2**
Density $\rho(Kg/m^3)$	998.2	3600	6500	4850	2220
Dynamic viscosity, $\mu(Ns/m^2)$	1.00E-03	0	0	0	0
Thermal conductivity, $k\ (W/m.K)$	0.60192	36	20	7.44	1.4
Specific heat, $C_P(J/kg.K)$	4182	765	535.6	544.2	745

this experimental study investigates the critical heat flux (CHF) of high-velocity circular jet impingement boiling on the nano-characteristic surface of the stagnation zone with different surface wet ability. The wet ability of the copper surface is varied to hydrophilic or hydrophobic nano-characteristic surfaces by modifying surface topography and chemistry [32].

The effect of impact velocity, sub cooling and solid–liquid contact angle (CA) on the CHF are studied thoroughly. The experimental relation ship between (CA) and CHF of the heat transfer surface is summarized by further discussion. The semi-the or ethical correlations proposed by the author previously for predicting the CHF of saturated and sub cooled circular jet impingement boiling on the stagnation zone are improved and expanded to higher impact velocity and wider CA range. The comparison results indicate the predicted value of the improved correlation sages well with the experimental data[33].

Effects of outlet port positions on the jet liquid impingement heat transfer characteristics in the mini-rectangular fin heat sink are numerically investigated. The three-dimensional governing equations for fluid flow and heat transfer characteristics are solved using finite volume scheme. The standard k-ε turbulent model is employed to solve the model for describing the heat transfer behaviors. The predicted results obtained from the model are verified by the measured data. The predicted results are in reasonable agreement with the measured data. The outlet port positions have a significant effect on the uniformities in velocity and temperature. Based on the results from this study, it is expected to lead to guidelines that will allow the design of the cooling system to ensure the electronic devices at the safe operating temperature.

Nanofluids, because of their enhanced heat transfer capability as compared to normal water/glycol/oil based fluids, offer the engineer opportunities for development in areas where high heat transfer, low temperature tolerance and small component size are required. In this present paper, the hydrodynamic and thermal fields of (water–AL_2O_3) nanofluid in a radial laminar flow cooling system are considered. Results indicate that considerable heat transfer enhancement is possible, even achieving a twofold increase in the case of a 10% nanoparticle volume fraction nanofluid. On the other hand, an increase in wall shear stress is also noticed with an increase in particle volume concentration [34].

In this experimental study, a jet of (AL_2O_3–water) nanofluid at various volume fractions (0.02%, 0.05%, 0.1%, and 0.15%) was used to impinge vertically on the vertex of a V-shaped plate. The heat transfer coefficient of the nanofluid jet was measured and its value was compared with that of water. The tests were performed under a laminar flow regime with Reynolds numbers ranging from (1732 to 2719). Results show that using (AL_2O_3–water) nanofluid at low volume fractions of 0.02% and 0.05% yield enhancements on both local and average heat transfer coefficients, and these positive effects increase with increasing Reynolds number. For nanofluids containing higher volume fractions of (0.1% and 0.15%), there were negative affect son the heat transfer coefficient. At Reynolds numbers from (1732 to 2250), the reduction in local and average heat transfer coefficient have been further decreased with increasing Reynolds number. However, at Reynolds numbers greater than 2250, these adverse effects were decreased and the heat transfer coefficient has increased, indicating that the use of nanofluid has resulted in an increase in the heat transfer coefficient. The maximum increase in the local and average heat transfer coefficients, as compared with those of water, were obtained in the case of nanofluid with the volume fraction of (0.05%, were 21.7% and13. 91%) respectively [35].

Determined experimentally the thermal conductivity of three nanofluids (aluminum oxide AL_2O_3 copper oxide CuO and zinc oxide ZnO) and developed a new correlations. The nanoparticles dispersed in a base fluid of 60:40 (by mass) ethylene glycol and water mixture. Particle volumetric concentration tested was up to 10% and the temperature range of the experiments was from 298 to 363 K. The results showed an increase in the thermal conductivity of nanofluids compared to the base fluids with an increasing volumetric concentration of nanoparticles. The thermal conductivity also increased substantially with increased in temperature[37].

Addressed the unique features of nanofluids, such as enhancement of heat transfer, improvement in thermal conductivity, increase in surface volume ratio, Brownian motion, thermophysical prophesies. They summarized the recent research in experimental and theoretical studies on forced and free convective heat transfer in nanofluids, their thermo-physical properties and their applications, and identify the challenges and opportunities for future research. From the results it was noted that the nanofluids had greater potential for heat transfer enhancement and were highly suited to application in practical heat transfer processes. The main reason for the heat transfer enhancement of nanofluids was that the suspended nanoparticles increase the thermal conductivity of the fluids, and the chaotic movement of ultrafine particles increases fluctuation and turbulence of the fluids, which accelerates the energy exchange process. Convective heat transfer is enhanced by increasing the particle concentration and the Reynolds number [38] .

Studied the influence of temperature and concentration of nanofluids on thermo physical properties, heat transfer and pumping power. The Prandtl number, Reynolds number and Nusselt number were functions of thermo-physical properties of nanofluids and these numbers strongly influence the convective heat transfer coefficient. The thermo physical properties varied with temperature and volumetric concentration of nanofluids. Therefore, a comprehensive analysis had been performed to evaluate the effects on the performance of nanofluids due to variations of density, specific heat, thermal conductivity and viscosity, which were functions of nanoparticle volume concentration and temperature [39].

Studied the application of computational fluid dynamics (CFD) for nanofluids in order to evaluate the heat transfer enhancement. This newly introduced category of cooling fluids containing ultrafine nanoparticles (1–100 nm) had displayed fascinating behavior during experiments including increased thermal conductivity and augmented heat transfer coefficient compared to a pure fluid. Most of these computational simulations were in acceptable concordance with the results from experiments[40].

Studied the development of new correlations for convective heat transfer and friction factor in turbulent regime for nanofluids. The experiments of nanoparticles comprised of aluminum oxide, copper oxide and silicon dioxide dispersed in 60% ethylene glycol and 40% water by mass. The rheological and the thermophysical properties such as viscosity, density, specific heat and thermal conductivity were measured at different temperatures for varying particle volume concentrations. The pressure loss was also measured and a new correlation was developed to represent the friction factor for nanofluids. The experiments results showed that the heat transfer coefficient of nanofluids increased with increased the particle volumetric concentration. The increase in the viscosity of the nanofluid with concentration led to increase heat transfer and pressure loss [41].

Studied experimentally the influence of AL_2O_3 nanofluid flowing in a circular tube on heat transfer. The experiments were conducted using AL_2O_{33}-water nanofluid (dp = 47 nm; volume concentration ϕ up to 0.1%) to evaluate the heat transfer coefficient and friction factor in a circular tube with twisted tape inserts in the transition flow regime. The experiments results showed that at Reynolds numbers of 3000 and 9000, the heat transfer enhancement in circular tube with 0.1% particle volume concentration were 13.77% and 23.69% respectively when compared to water. Furthermore, for the same particle volume concentration of 0.1%, the heat transfer enhancement with twisted tape insert inside a circular tube were 36.96% and 44.71% at Reynolds numbers of 3000 and 9000 respectively, when compared to flow of nanofluid in a plain tube [42].

The thermal conductivity of nanofluids varies with the size, shape, and material of nanoparticles dispersed in the base fluids. For example, nanofluids with metallic nanoparticles were found to have a higher thermal conductivity than nanofluids with non-metallic (oxide) nanoparticles. The smaller nanoparticle diameter provided the higher thermal conductivities of nanofluids. Nanofluids are solid-liquid composite materials consisting of solid nanoparticles with sizes typically of 1 to 100 nm suspended in liquid. The nanofluid is not a simple liquid-solid mixture; the most important criterion of nanofluid is agglomerate-free stable suspension for long durations without causing any chemical changes in the base fluid. This can be achieved by minimizing the density between solids and liquids or by increasing the viscosity of the liquid; by using nanometer-sized particles and by preventing particles from agglomeration, the settling of particles can be avoided. Nanofluids have attracted great interest recently because of reports of enhanced thermal properties [43].

Preparation of nanofluids is an important step in the use of nanoparticles to improve the thermal conductivity of conventional heat transfer fluids. Researchers have experimented different types of nanoparticles such as metallic particles (Cu, Al, Fe, Au, and Ag), non-metallic particles (Al2O3, CuO, Fe3O4, TiO2, and SiO2) [44].

The heat transfer rate can passively be enhanced by improving thermophysical properties with adding small solid particles in the fluid. Maxwell was the first to show the possibility of increasing thermal conductivity of a solid/liquid mixture by more volume fraction of solid particles. He used particle of micrometer or millimeter dimensions. Those particles were the cause of numerous problems, such as abrasion, clogging, high pressure drop and poor suspension stability. Therefore, a new class of fluid for improving thermal conductivity and avoiding adverse effects due to the presence of particles is required. To meet these important requirements, a new class of fluids, called nanofluids [45], has been developed. Nanofluids are liquid suspensions of nano-sized particles. These particles have attracted significant attention since anomalously large enhancements in effective thermal conductivity at low particles concentration were reported.

Addressed the unique features of nanofluids, such as enhancement of heat transfer, improvement in thermal conductivity, increase in surface volume ratio, Brownian motion, thermophysical prophesies. They summarized the recent research in experimental and theoretical studies on forced and free convective heat transfer in nanofluids, their thermo-physical properties and their applications, and identify the challenges and opportunities for future research. From the results it was noted that the nanofluids had greater potential for heat transfer enhancement and were highly

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